

TITLEIMPROVED PROCESS FOR PRODUCING  $\alpha$ -OLEFINSFIELD OF THE INVENTION

A process stream from the synthesis of  $\alpha$ -olefins from ethylene using a  
5 late transition metal complex of a tridentate ligand as (part of) the catalyst  
system for oligomerizing ethylene is deactivated using a protic organic com-  
pound having a specified pKa.

TECHNICAL BACKGROUND

$\alpha$ -Olefins are important items of commerce, hundreds of millions of  
10 kilograms being manufactured yearly. They are useful as monomers for  
(co)polymerizations and as chemical intermediates for the manufacture of  
many other materials, for example detergents and surfactants. Presently  
most  $\alpha$ -olefins are made by the catalyzed oligomerization of ethylene by vari-  
ous catalysts, especially certain nickel complexes or aluminum alkyls, see for  
15 instance US4020121 and I. Kroschwitz, et al., Ed., Kirk-Othmer Encyclopedia  
of Chemical Technology, 4<sup>th</sup> Ed., Vol. 17, John Wiley & Sons, New York, pp.  
839-858. Recently, as reported in U.S. Patent 6103946, which is hereby in-  
corporated by reference, it has been found that iron complexes of certain tri-  
dentate ligands of 2,6-pyridinecarboxaldehyes or 2,6-diacylpyridines are ex-  
20 cellent catalysts for the production of  $\alpha$ -olefins from ethylene. U.S. Patent  
Application Publications 2002/0016521 and 2002019575, both of which are  
hereby included by reference, describe a manufacturing process for  $\alpha$ -olefins  
using these catalysts in which a liquid full continuous stirred tank reactor is  
used, optionally followed by a final reactor which may be plug flow reactor.  
25 No mention is made of deactivation of the process stream with organic com-  
pounds.

SUMMARY OF THE INVENTION

This invention concerns, a process for the preparation of  $\alpha$ -olefins by  
the catalyzed oligomerization of ethylene using as part of a catalyst system a  
30 complex late transition metal with a tridentate ligand wherein a process  
stream comprising said  $\alpha$ -olefins and said catalyst system is produced,  
wherein the improvement comprises, deactivating said catalyst system by

adding to said process stream one or more organic compounds (deactivating agents) having a pKa of about 2 to about 20.

#### DETAILS OF THE INVENTION

Herein, certain terms are used. Some of them are:

5 A "hydrocarbyl group" is a univalent group containing only carbon and hydrogen. As examples of hydrocarbyls may be mentioned unsubstituted alkyls, cycloalkyls and aryls. If not otherwise stated, it is preferred that hydrocarbyl groups (and alkyl groups) herein contain 1 to about 30 carbon atoms.

10 By "substituted hydrocarbyl" herein is meant a hydrocarbyl group that contains one or more substituent groups which are inert under the process conditions to which the compound containing these groups is subjected (e.g., an inert functional group, see below). The substituent groups also do not substantially detrimentally interfere with the oligomerization process or operation of the oligomerization catalyst system. If not otherwise stated, it is preferred that substituted hydrocarbyl groups herein contain 1 to about 30 carbon atoms. Included in the meaning of "substituted" are rings containing one or 15 more heteroatoms, such as nitrogen, oxygen and/or sulfur, and the free valence of the substituted hydrocarbyl may be to the heteroatom. In a substituted hydrocarbyl, all of the hydrogens may be substituted, as in trifluoromethyl.

20

25 By "(inert) functional group" herein is meant a group, other than hydrocarbyl or substituted hydrocarbyl, which is inert under the process conditions to which the compound containing the group is subjected. The functional groups also do not substantially deleteriously interfere with any process described herein that the compound in which they are present may take part in. Examples of functional groups include halo (fluoro, chloro, bromo and iodo), and ether such as  $-OR^{50}$  wherein  $R^{50}$  is hydrocarbyl or substituted hydrocarbyl. In cases in which the functional group may be near a transition metal atom, the functional group alone should not coordinate to the metal atom 30 more strongly than the groups in those compounds that are shown as coordinating to the metal atom, that is they should not displace the desired coordinating group.

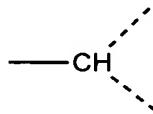
By a "cocatalyst" or a "catalyst activator" is meant one or more compounds that react with a transition metal compound to form an activated catalyst species. One such catalyst activator is an "alkyl aluminum compound" which, herein, means a compound in which at least one alkyl group is bound to an aluminum atom. Other groups such as, for example, alkoxide, hydride, an oxygen atom bridging two aluminum atoms, and halogen may also be bound to aluminum atoms in the compound.

By a "linear  $\alpha$ -olefin product" is meant a composition predominantly comprising a compound or mixture of compounds of the formula

10  $H(CH_2CH_2)_qCH=CH_2$  wherein  $q$  is an integer of 1 to about 18. In most cases, the linear  $\alpha$ -olefin product of the present process will be a mixture of compounds having differing values of  $q$  of from 1 to 18, with a minor amount of compounds having  $q$  values of more than 18. Preferably less than 50 weight percent, and more preferably less than 20 weight percent, of the product will have  $q$  values over 18. The product may further contain small amounts (preferably less than 30 weight percent, more preferably less than 10 weight percent, and especially preferably less than 2 weight percent) of other types of compounds such as alkanes, branched alkenes, dienes and/or internal olefins.

20 By a "primary carbon group" herein is meant a group of the formula  $-CH_2---$ , wherein the free valence  $---$  is to any other atom, and the bond represented by the solid line is to a ring atom of a substituted aryl to which the primary carbon group is attached. Thus the free valence  $---$  may be bonded to a hydrogen atom, a halogen atom, a carbon atom, an oxygen atom, a sulfur atom, etc. In other words, the free valence  $---$  may be to hydrogen, hydrocarbyl, substituted hydrocarbyl or a functional group. Examples of primary carbon groups include  $-CH_3$ ,  $-CH_2CH(CH_3)_2$ ,  $-CH_2Cl$ ,  $-CH_2C_6H_5$ ,  $-OCH_3$  and  $-CH_2OCH_3$ .

By a "secondary carbon group" is meant the group

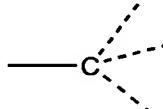


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wherein the bond represented by the solid line is to a ring atom of a substituted aryl to which the secondary carbon group is attached, and both free

bonds represented by the dashed lines are to an atom or atoms other than hydrogen. These atoms or groups may be the same or different. In other words the free valences represented by the dashed lines may be hydrocarbyl, substituted hydrocarbyl or inert functional groups. Examples of secondary 5 carbon groups include  $-\text{CH}(\text{CH}_3)_2$ ,  $-\text{CHCl}_2$ ,  $-\text{CH}(\text{C}_6\text{H}_5)_2$ , cyclohexyl,  $-\text{CH}(\text{CH}_3)\text{OCH}_3$ , and  $-\text{CH}=\text{CCH}_3$ .

By a "tertiary carbon group" is meant a group of the formula

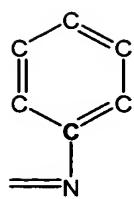


wherein the bond represented by the solid line is to a ring atom of a substituted 10 aryl to which the tertiary carbon group is attached, and the three free bonds represented by the dashed lines are to an atom or atoms other than hydrogen. In other words, the bonds represented by the dashed lines are to hydrocarbyl, substituted hydrocarbyl or inert functional groups. Examples of 15 tertiary carbon groups include  $-\text{C}(\text{CH}_3)_3$ ,  $-\text{C}(\text{C}_6\text{H}_5)_3$ ,  $-\text{CCl}_3$ ,  $-\text{CF}_3$ ,  $-\text{C}(\text{CH}_3)_2\text{OCH}_3$ ,  $-\text{C}\equiv\text{CH}$ ,  $-\text{C}(\text{CH}_3)_2\text{CH}=\text{CH}_2$ , aryl and substituted aryl such as phenyl and 1-adamantyl.

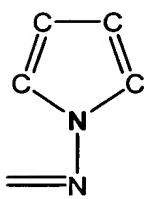
By "aryl" is meant a monovalent aromatic group in which the free valence is to the carbon atom of an aromatic ring. An aryl may have one or more aromatic rings, which may be fused, connected by single bonds or other 20 groups.

By "substituted aryl" is meant a monovalent aromatic group substituted as set forth in the above definition of "substituted hydrocarbyl". Similar to an aryl, a substituted aryl may have one or more aromatic rings which may be fused, connected by single bonds or other groups; however, when the substituted 25 aryl has a heteroaromatic ring, the free valence in the substituted aryl group can be to a heteroatom (such as nitrogen) of the heteroaromatic ring instead of a carbon.

By a "first ring atom in  $\text{R}^6$  and  $\text{R}^7$  bound to an imino nitrogen atom" is meant the ring atom in these groups bound to an imino nitrogen shown in (I), 30 for example

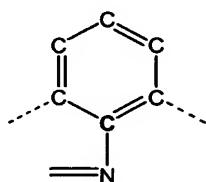


(II) or

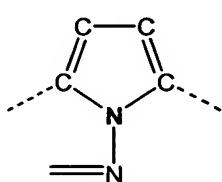


(III)

the atoms shown in the 1-position in the rings in (II) and (III) are the first ring atoms bound to an imino carbon atom (other groups which may be substituted on the aryl groups are not shown). Ring atoms adjacent to the first ring atoms are shown, for example, in (IV) and (V), where the open valencies to these adjacent atoms are shown by dashed lines [the 2,6-positions in (IV) and the 2,5-positions in (V)].



(IV) or



(V)

By "pKa" herein is meant the usual meaning, the pH at which a Bronsted acid is half in the protic form and half in the ionized form, in dilute solution. pKas of about 14 or less can be measured by well-known methods in dilute aqueous solution. pKas above about 14 may be measured by methods described in F. G. Bordwell, *Acc. Chem. Res.*, vol. 21, p. 456-463 (1988). Organic compounds within the appropriate pKa range are sometimes called "protic" compounds herein.

By "deactivation" herein is meant that (at least some of) the oligomerization catalyst (system) is no longer able to oligomerize ethylene. In other words the catalyst is rendered inert towards ethylene. The deactivation may be partial so that only some of the oligomerization catalyst is deactivated or all of the oligomerization catalyst is deactivated. Due to the chemical nature of the active catalyst and cocatalyst(s) (if any) present, cocatalyst(s) may also be deactivated by the protic compound used herein. By "complete deactivation" herein is meant all oligomerization catalyst and all cocatalyst(s) are completely deactivated (see below).

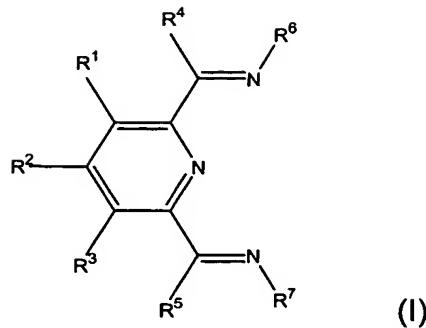
By a "tridentate ligand" is meant is neutral organic compound having three heteroatoms (atoms other than carbon and hydrogen) which are in a position to potentially complex with a late transition metal. Such heteroatoms include nitrogen, oxygen, sulfur and phosphorous.

By a "late transition metal" herein is meant a metal of Group 7 through Group 12 of the periodic table (IUPAC notation). Preferred late transition metals are Co and Fe, and Fe is especially preferred.

By an "alkylaluminum compound" herein is meant a compound having 5 at least one alkyl group bound directly to an aluminum atom. Other elements such as halogen (especially chlorine) and oxygen may be present in the compound. Useful alkylaluminum compounds include trialkylaluminum compounds such as trimethylaluminum, triethylaluminum and tri-i-butylaluminum, aluminoxanes such as methyl aluminoxanes, and dialkylhaloaluminum compounds such as diethylaluminum chloride and ethylaluminum sesquichloride. 10

Generally speaking processes to make linear  $\alpha$ -olefins with the catalysts described herein are often similar. Ethylene and the metal complex together with optional ingredients solvent and cocatalyst(s) are added and mixed in a vessel. The reaction may then take place in that vessel and possibly other vessels as the process stream moves through the plant. During that 15 time more ethylene and/or metal complex and/or solvent and/or cocatalysts(s) may be added at one or more other points in the process. At some point the synthesis of the  $\alpha$ -olefins is complete and/or it is desirable to stop the oligomerization, so the process stream is directed out of the oligomerization reactor(s). Oftentimes at this point excess ethylene is vented or stripped from 20 the process stream and/or the reactive catalyst components are removed by washing with water or other aqueous solution, and then the process stream, which includes linear  $\alpha$ -olefins and solvent (if present) is fractionally distilled through a series of distillation columns to isolate pure  $\alpha$ -olefins and/or groups 25 of  $\alpha$ -olefins. While many variations are possible, most processes have these basic elements.

A preferred tridentate complex herein is an iron or cobalt, especially iron, complex of a 2,6-pyridinedicarboxaldehyebisimine or a 2,6-diacylpyridinebisimine. Such a preferred ligand may have the formula



wherein:

5       $R^1$ ,  $R^2$  and  $R^3$  are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl or an inert functional group, provided that any two of  $R^1$ ,  $R^2$  and  $R^3$  vicinal to one another taken together may form a ring;

$R^4$  and  $R^5$  are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl or an inert functional group;

$R^6$  and  $R^7$  are each independently a substituted aryl having a first ring atom bound to the imino nitrogen, provided that:

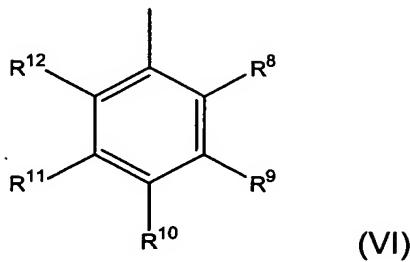
10      in  $R^6$ , a second ring atom adjacent to said first ring atom is bound to a halogen, a primary carbon group, a secondary carbon group or a tertiary carbon group; and further provided that

15      in  $R^6$ , when said second ring atom is bound to a halogen or a primary carbon group, none, one or two of the other ring atoms in  $R^6$  and  $R^7$  adjacent to said first ring atom are bound to a halogen or a primary carbon group, with the remainder of the ring atoms adjacent to said first ring atom being bound to a hydrogen atom; or

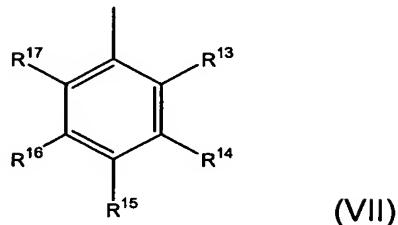
20      in  $R^6$ , when said second ring atom is bound to a secondary carbon group, none, one or two of the other ring atoms in  $R^6$  and  $R^7$  adjacent to said first ring atom are bound to a halogen, a primary carbon group or a secondary carbon group, with the remainder of the ring atoms adjacent to said first ring atom being bound to a hydrogen atom; or

25      in  $R^6$ , when said second ring atom is bound to a tertiary carbon group, none or one of the other ring atoms in  $R^6$  and  $R^7$  adjacent to said first ring atom are bound to a tertiary carbon group, with the remainder of the ring atoms adjacent to said first ring atom being bound to a hydrogen atom.

In one preferred compound (I)  $R^6$  is



and  $R^7$  is



5 wherein:

$R^8$  is a halogen, a primary carbon group, a secondary carbon group or a tertiary carbon group; and

$R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$  and  $R^{17}$  are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl or a functional group;

10 provided that:

when  $R^8$  is a halogen or primary carbon group none, one or two of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  are a halogen or a primary carbon group, with the remainder of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  being hydrogen; or

when  $R^8$  is a secondary carbon group, none or one of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  15 is a halogen, a primary carbon group or a secondary carbon group, with the remainder of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  being hydrogen; or

when  $R^8$  is a tertiary carbon group, none or one of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  is tertiary carbon group, with the remainder of  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  being hydrogen; and further provided that any two of  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$  20 and  $R^{17}$  vicinal to one another, taken together may form a ring.

In the above formulas (VI) and (VII),  $R^8$  corresponds to the second ring atom adjacent to the first ring atom bound to the imino nitrogen, and  $R^{12}$ ,  $R^{13}$  and  $R^{17}$  correspond to the other ring atoms adjacent to the first ring atom.

In compounds (I) containing (VI) and (VII), it is particularly preferred 25 that:

if R<sup>8</sup> is a primary carbon group, R<sup>13</sup> is a primary carbon group, and R<sup>12</sup> and R<sup>17</sup> are hydrogen; or

if R<sup>8</sup> is a secondary carbon group, R<sup>13</sup> is a primary carbon group or a secondary carbon group, more preferably a secondary carbon group, and R<sup>12</sup> and R<sup>17</sup> are hydrogen; or

if R<sup>8</sup> is a tertiary carbon group (more preferably a trihalo tertiary carbon group such as a trihalomethyl), R<sup>13</sup> is a tertiary carbon group (more preferably a trihalotertiary group such as a trihalomethyl), and R<sup>12</sup> and R<sup>17</sup> are hydrogen; or

10 if R<sup>8</sup> is a halogen, R<sup>13</sup> is a halogen, and R<sup>12</sup> and R<sup>17</sup> are hydrogen.

In all specific preferred compounds (I) in which (VI) and (VII) appear, it is preferred that R<sup>1</sup>, R<sup>2</sup> and R<sup>3</sup> are hydrogen; and/or R<sup>4</sup> and R<sup>5</sup> are methyl. It is further preferred that:

15 R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is methyl; and R<sup>8</sup> is a primary carbon group, more preferably methyl; or

R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is ethyl; and R<sup>8</sup> is a primary carbon group, more preferably ethyl; or

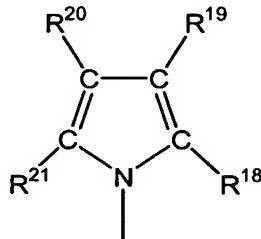
R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is isopropyl; and R<sup>8</sup> is a primary carbon group, more preferably isopropyl; or

20 R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is n-propyl; and R<sup>8</sup> is a primary carbon group, more preferably n-propyl; or

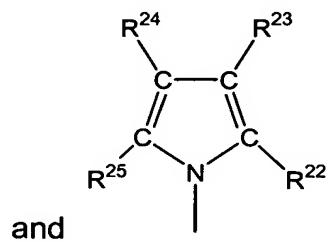
R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is chloro; and R<sup>8</sup> is a halogen, more preferably chloro; or

25 R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>17</sup> are all hydrogen; R<sup>13</sup> is trihalomethyl, more preferably trifluoromethyl; and R<sup>8</sup> is a trihalomethyl, more preferably trifluoromethyl.

In another preferred embodiment of (I), R<sup>6</sup> and R<sup>7</sup> are, respectively



(VIII)



(IX)

wherein:

$R^{18}$  is a halogen, a primary carbon group, a secondary carbon group or a tertiary carbon group; and

$R^{19}$ ,  $R^{20}$ ,  $R^{23}$  and  $R^{24}$  are each independently hydrogen, hydrocarbyl,  
5 substituted hydrocarbyl or a functional group; and  
provided that:

when  $R^{18}$  is a halogen or primary carbon group none, one or two of  $R^{21}$ ,  
 $R^{22}$  and  $R^{25}$  are a halogen or a primary carbon group, with the remainder of  
 $R^{21}$ ,  $R^{22}$  and  $R^{25}$  being hydrogen; or

10 when  $R^{18}$  is a secondary carbon group, none or one of  $R^{21}$ ,  $R^{22}$  and  $R^{25}$   
is a halogen, a primary carbon group or a secondary carbon group, with the  
remainder of  $R^{21}$ ,  $R^{22}$  and  $R^{25}$  being hydrogen;

15 when  $R^{18}$  is a tertiary carbon group, none or one of  $R^{21}$ ,  $R^{22}$  and  $R^{25}$  is  
a tertiary carbon group, with the remainder of  $R^{21}$ ,  $R^{22}$  and  $R^{25}$  being hydro-  
gen;

and further provided that any two of  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$  and  
 $R^{25}$  vicinal to one another, taken together may form a ring.

In the above formulas (VIII) and (IX),  $R^{18}$  corresponds to the second  
ring atom adjacent to the first ring atom bound to the imino nitrogen, and  $R^{21}$ ,  
20  $R^{22}$  and  $R^{25}$  correspond to the other ring atoms adjacent to the first ring atom.

In compounds (I) containing (VIII) and (IX), it is particularly preferred  
that:

if  $R^{18}$  is a primary carbon group,  $R^{22}$  is a primary carbon group, and  $R^{21}$   
and  $R^{25}$  are hydrogen; or

25 if  $R^{18}$  is a secondary carbon group,  $R^{22}$  is a primary carbon group or a  
secondary carbon group, more preferably a secondary carbon group, and  $R^{21}$   
and  $R^{25}$  are hydrogen; or

30 if  $R^{18}$  is a tertiary carbon group (more preferably a trihalo tertiary car-  
bon group such as a trihalomethyl),  $R^{22}$  is a tertiary carbon group (more pref-  
erably a trihalotertiary group such as a trihalomethyl), and  $R^{21}$  and  $R^{25}$  are hy-  
drogen; or

if  $R^{18}$  is a halogen,  $R^{22}$  is a halogen, and  $R^{21}$  and  $R^{25}$  are hydrogen.

In all specific preferred compounds (I) in which (VIII) and (IX) appear, it is preferred that R<sup>1</sup>, R<sup>2</sup> and R<sup>3</sup> are hydrogen; and/or R<sup>4</sup> and R<sup>5</sup> are methyl. It is further preferred that:

5 R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>23</sup> and R<sup>24</sup> are all hydrogen; R<sup>22</sup> is methyl; and R<sup>18</sup> is a primary carbon group, more preferably methyl; or

R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>23</sup> and R<sup>24</sup> are all hydrogen; R<sup>22</sup> is ethyl; and R<sup>18</sup> is a primary carbon group, more preferably ethyl; or

R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>23</sup> and R<sup>24</sup> are all hydrogen; R<sup>22</sup> is isopropyl; and R<sup>18</sup> is a primary carbon group, more preferably isopropyl; or

10 R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>23</sup> and R<sup>24</sup> are all hydrogen; R<sup>22</sup> is n-propyl; and R<sup>18</sup> is a primary carbon group, more preferably n-propyl; or

R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>23</sup> and R<sup>24</sup> are all hydrogen; R<sup>22</sup> is chloro or bromo; and R<sup>18</sup> is a halogen, more preferably chloro or bromo.

15 Compound (I) and its iron complexes (the oligomerization catalyst) may be prepared by a variety of methods, see for instance previously incorporated US5955555 and WO99/02472, as well as WO99/50273 (equivalent to United States Patent Application Serial No. 09/277,910, filed March 29, 1999) and WO00/08034, all of which are also included by reference.

20 The use of 2,6-pyridinecarboxaldehyde or 2,6-diacylpyridine complexes as ethylene oligomerization and/or polymerization catalysts, and the general conditions for such reactions, including temperature, pressure, supportation of the iron complex (if desired), useful cocatalysts and amounts, much of which is useful herein, may be found in U.S. Patents 5,955,555, 6,103,946, World Patent Applications 02/06192, 02/12151, 01/58874 and 02/00339, and U.S. 25 Provisional Patent Applications 60/285,554 filed Apr. 20, 2001 (CL1844 PRV1) and 60/411,449 filed Sept. 17, 2003 (CL2151 PRV), all of which are hereby included by reference. Another type of useful tridentate late transition metal complex is found in World Patent Application 02/34710 which is also hereby included by reference.

30 The process may be run in an inert solvent such as a hydrocarbon. Useful hydrocarbons include alkanes such as heptane, or nonane, or aromatic hydrocarbons such as toluene or xylene. Preferably the solvent has a boiling point that allows it be readily separated by distillation from the  $\alpha$ -olefins pro-

duced in the process. The “solvent” for the process may be some or all of the  $\alpha$ -olefins produced in the process. They may be formed in situ and/or added at some point during the process.

Cocatalysts are also often used in the oligomerization process. Typically these cocatalysts are compounds that are alkylating or hydriding agents such as one or more alkylaluminum compounds or metal hydrides, respectively. Alkylaluminum compounds are probably the most common type of cocatalysts. These cocatalysts are believed to react with the late transition metal complex to form complexes, which are the actual active oligomerization catalysts. These active oligomerization catalysts are believed to (mostly) have alkyl and/or hydride groups bonded to the transition metal atom. Typically these cocatalysts are added in molar excess (of the transition metal complex) to both ensure reaction with the late transition metal complex and to remove the last traces of catalyst poisons from the reaction system. In order to completely deactivate at the catalyst, it is preferred to add a stoichiometric excess of the organic protic deactivating agent, that is more than one mole of “active protons” per equivalent of activating groups (alkyl, hydride, etc.). For example if the deactivating compound was an alcohol,  $R^{60}OH$ , wherein  $R^{60}$  is alkyl, it would take 3 moles of  $R^{60}OH$  to completely deactivate one mole of alkylaluminum compound  $R^{61}3Al$  wherein  $R^{61}$  is alkyl. Therefore a stoichiometric amount, preferably a stoichiometric excess, of deactivating agent is used to completely deactivate the process stream.

The amount of deactivating agent needed for partial or complete deactivation of the catalyst components may be easily determined by titration of the appropriate process stream with the deactivating agent itself.

The deactivating agent has a pKa of about 2 to about 20, preferably about 3 to about 18. Useful types of deactivating agents include alcohols, phenols (compounds having hydroxy groups bound to aromatic ring carbon atoms), carboxylic acids, and relatively acidic aldehydes. Alcohols and carboxylic acids are preferred deactivating agents. The deactivating agent may be monofunctional (have one protic group present) or polyfunctional (such as a diol or triol). Monofunctional deactivating agents are preferred. Preferably the deactivating agent and its reaction product(s) with any of the compounds it

may deactivate [for example deactivating  $R^{61}Al$  with  $R^{60}OH$  may give formation of  $(R^{60}O)_3Al$  and  $R^{61}H$ ;  $R^{61}H$  is typically a lower alkane and therefore volatile and inert] are soluble in the process stream. The process stream will usually predominantly be solvent (if used) and product  $\alpha$ -olefins.

5       Typically the series of  $\alpha$ -olefins produced in this type of process is separated (into pure olefins or groups of olefins) by fractional distillation through multiple distillation columns. Preferably the deactivating agent has a boiling point of about 170°C or more at a pressure of 2 kPa, more preferably about 220°C or more at a pressure of 2 kPa, and especially preferably about 10 250°C or more at a pressure of 2 kPa. When such a low volatility compound is used as the deactivating compound it typically will not codistill with any of the usually isolated olefin fractions, thereby eliminating the problem of having an undesirable impurity in one or more of the purified product streams. It also will not appreciably contaminate any gaseous recycle streams, such as a re- 15 cycle ethylene stream, thereby reducing or even eliminating the purification capacity needed to purify such streams. Finally since the residues from the catalyst deactivation typically will end up in the still bottoms from the final distillation column, and these are often burned for their fuel value, there is no separate waste stream of catalyst deactivation products as there is, for example, using an aqueous based wash.

20       The deactivating agent may be added to the process stream at any point after it is desired to stop the oligomerization reaction. Typically this will be on exiting the (final) reactor in which oligomerization takes place and before entering the first product distillation column. It may be added before or 25 after excess ethylene in the process stream is removed (flashed off), or may be added after some of the excess ethylene is flashed off. Since the deactivating compound may have a low volatility, in that instance it will not appreciably contaminate the recycle ethylene. The deactivating agent, particularly if it is a liquid, may be added neat to the process stream, or it may be added as 30 a solution in a solvent, particularly if the solvent is a compounds or compounds already present in the process (solvent in the process or one or more  $\alpha$ -olefins). Preferably the deactivating agent is mixed with the process stream

so that, particularly if complete deactivation is desired, the agent will contact all "parts" of that stream.

Useful deactivating agents include octadecanol, stearic acid, bisphenol-A, saccharin, sulfanilic acid, thioacetic acid, ethylene glycol, 1-napthoic acid, and 1-octacosanol. Since many high boiling "compounds" are sold as mixtures because they are difficult to purify by distillation or other means, such mixtures are also useful, and sometimes preferred for economic reasons (lower cost).

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